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GABBRO SOILS AND PLANT DISTRIBUTIONS ON THEM

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Abstract

Gabbro is a mafic rock with many species that do not occur on soils of granitic or ultramafic rocks. Although some gabbro soils harbor many unique or endemic species, others do not, as botanists have noted from the Appalachian Piedmont to the mountains of California and Oregon. Gabbro soils were sampled in the Peninsular Ranges and in the foothills of the Sierra Nevada to identify special features of the gabbro soils with unique plant species distributions. No soil morphological or chemical differences were found between gabbro soils with and without unique plant species that might explain the differences in plant distributions. Although many unique species may occur only on gabbro soils, apparently their distributions cannot be explained primarily by soil differences among gabbro soils.

Key Words: Gabbro, rare plant species, rocks, soils.

Some soils with gabbro parent materials have unique plant associations (Hunter and Horenstein 1992; Oberbauer 1993), or have plant communities that are intermediate between those of soils on granitic and on ultramafic rocks (Whittaker 1960). Gabbro is a mafic plutonic rock with mineralogy and chemistry that spans the range between granitic rocks, which are silicic rather than mafic, and ultramafic rocks. Therefore, it is reasonable to expect plant communities of gabbro soils to have some aspects of those on granitic soils and some aspects of those on ultramafic rocks, as described by Whitaker (1960). However, no reasons have been found for some endemic species occurring on some gabbro soils and not on others.

Botanists in eastern North America have recognized that some soils with mafic soil parent materials have unique plant associations, especially on the Idedell soils (Dayton 1966). The Iredell series are common soils with mafic parent material on the Piedmont of eastern North America. Several pedons in soils mapped as Iredell were sampled in NRCS (Natural Resources Conservation Service) soil surveys and analyzed in an NRCS laboratory. Exchangeable Ca/Mg ratios <1 were found in most of those pedons, but the soil parent material was not identified specifically for any of the pedons. Ogg and Smith (1993) identified the parent material of a soil mapped as Iredell to be pyroxenite, and exchangeable Ca/Mg ratios <1 prevailed in it, but the ratios were not as low as in ultramafic soils sampled for the same investigation.

Although botanists have recognized unique vegetation on some gabbro soils and not on others, no soil differences have been discovered that might explain vegetation differences. A gabbro soils investigation was conducted to discovery soil differences related to vegetation differences in the Sierra Nevada and in the Peninsular Ranges and to evaluate soil properties that might explain why some gabbro soils have unique vegetation and others do not (Fig. 1).

The Nature of Gabbro

Gabbro is a petrologic term for plutonic rocks that consist of olivine or hornblende, pyroxene, and calcium-feldspar. Its composition spans the range between diorite and peridotite. Among the plutonic rocks, from granite to peridotite, diorite yields the most fertile soils because it has the most favorable balance of magnesium, potassium, and calcium. Soils with peridotite parent materials have very high magnesium and low calcium concentrations, making them much less favorable for most plants. Gabbro has higher concentrations of all ten of the first transition elements than more silicic rocks (Table 1), and some of those elements can be toxic to plants. Peridotite, however, has much greater concentrations of those elements that are most likely to be toxic (Cr, Co, and Ni). Because the composition of gabbro spans the range between diorite and peridotite, gabbro soils might be expected to range from quite fertile to unfavorable for many plants.

Gabbro has 10 to 90% feldspar, 5 to 90% pyroxene, and 5 to 90% olivine or hornblende (Le Maitre 2002). The feldspar is a calcic plagioclase and the pyroxene is mostly augite (monoclinic pyroxene). If the pyroxene is mostly enstatite or hypersthene (orthorhombic pyroxenes) the rock is called norite. Gabbro, with monoclinic pyroxenes, is much more common than norite in western North America. Rock compositions are commonly shown on triangular diagrams (Le Maitre 2002). Only three minerals can be shown on a triangular diagram; therefore separate

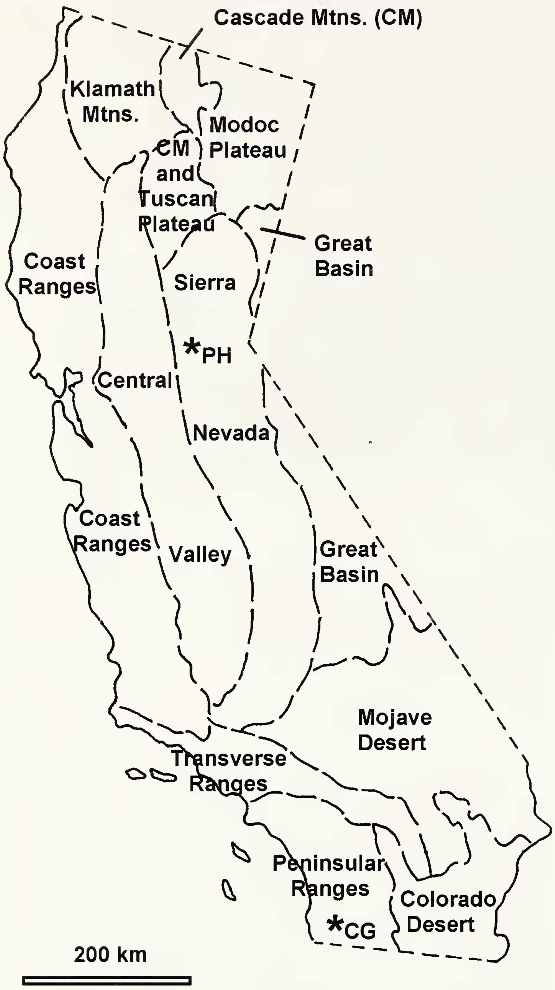

FIG. 1. Locations of the Pine Hill Preserve (PH) in the foothills of the Sierra Nevada and The Cuyamaca-Guatay area (CG) in the Peninsular Ranges Province, CA.

triangles are displayed for olivine gabbro (Fig. 2) and gabbro with hornblende (Fig. 3). Molar Ca/Mg ratios are plotted on Figs. 2 and 3. This requires assumptions about the compositions of the minerals. The compositions were assumed to be $Ca_{0.6}Na_{0.4}Al_{1.6}Si_{2.4}O_8$ for calcium plagioclase (which is designated An_{60} by petrologists), $Ca_{0.4}Mg_{0.4}Fe_{0.2}SiO_3$ for clinopyroxene (augite), $Mg_{1.8}Fe_{0.2}SiO_4$ for olivine, and $Ca_2Mg_3(Al,Fe)Al_2Si_6O_{22}(OH)_2$ for hornblende. The molar Ca/Mg ratios, based on these formulas are infinite for plagioclase, 1.0 for clinopyroxene, 0 for olivine, and 0.67 for hornblende. The molar Ca/Mg ratios of seven gabbro samples from the Pine Hill complex reported by Springer (1980) ranged from 0.58 to 0.76 and averaged 0.69 mol/mol. Olivine has more affect than plagioclase on the Ca/Mg ratios in Fig. 2, because Ca in the plagioclase is only 4.4 moles/kg while Mg in the olivine is 27.7 mol/kg.

TABLE 1. ELEMENTAL COMPOSITION OF GABBRO AND ITS NEIGHBORS—MORE SILICIC DIORITE AND LESS SILICIC PERIDOTITE. Mean composition of major elements from Le Maitre (1976) and first transition elements from Vinogradov (1962), who included andesite with diorite, basalt with gabbro, and dunite with peridotite. The first transition elements have outer electrons that are in d-orbitals. They are transitional from group 1 and 2 elements with outer electrons in s-orbitals (columns on left side of periodic table) and group 3 to 8 elements with outer electrons in p-orbitals (right side of periodic table of elements).

Major element	Diorite	Gabbro	Peridotite
		g/kg (ppt)	
Si	269	234	198
Al	88	82	22
Ti	6	7	5
Fe	55	80	76
Mn	1	1	3
Mg	22	46	188
Ca	47	67	36
Na	21	14	3
K	12	7	2
P	1.2	1.0	0.4
First trans. element		mg/kg (ppm)	
Sc	2	24	5
Ti	8000	9000	300
V	100	200	40
Cr	50	200	2000
Mn	1200	2000	1500
Fe	58,500	85,600	98,500
Co	10	45	200
Ni	55	160	2000
Cu	35	100	20
Zn	72	130	30

Gabbro Compositions in California

Gabbro occurs as components in ophiolites of accreted terranes, in stocks and Alaska-type intrusions, and in laterally extensive layered bodies. Botanists have described plant communities on gabbro in the intrusive bodies of the Peninsular Ranges (Beauchamp 1986; Oberbauer 1993; Cheng 2004) and the Pine Hill complex of the Sierra Nevada foothills (Hunter and Horenstein 1992). Gabbro of these intrusive bodies has been studied comprehensively by Miller (1937), Larsen (1948), and Wallawender (1976) in the Peninsular Ranges and by Springer (1980) in the Pine Hill complex.

Larsen (1948) gave the mineral compositions of 20 rock samples that are representative of gabbro and norite in the Santa Ana Mountains. All contained hornblende and most of them contained at least 10% hornblende, but only 5 samples contained olivine. A hornblende-free

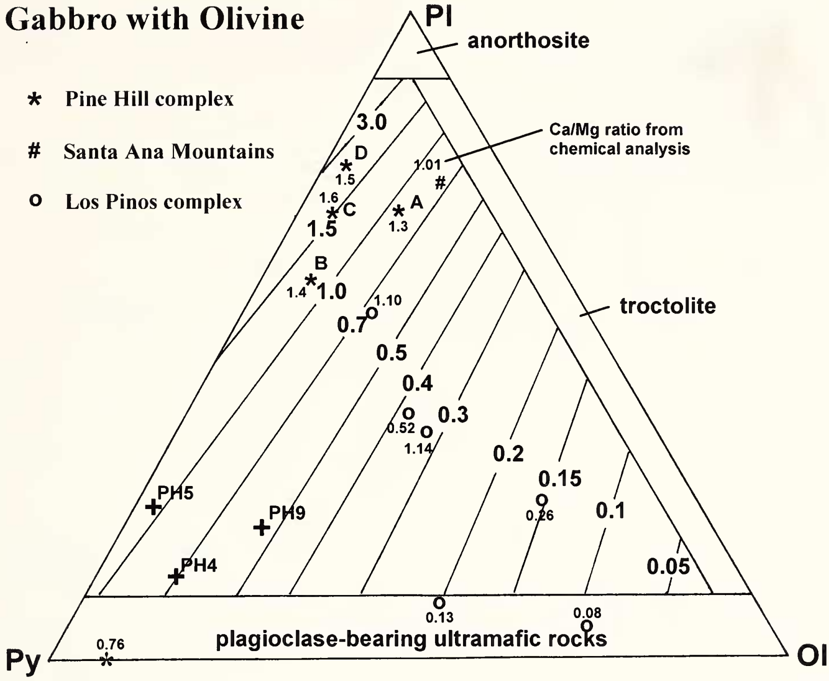

FIG. 2. Olivine-bearing gabbro. Molar Ca/Mg ratios (0.05–3.0) of gabbro composed of plagioclase (Pl), olivine (Ol), and pyroxene (Py). Plagioclase is represented by labradorite ($Ca_{0.6}Na_{0.4}Al_{1.6}Si_{2.4}O_8$), olivine by forsterite or chrysolite ($Mg_{1.8}Fe_{0.2}SiO_4$), and pyroxene by augite ($Ca_{0.4}Mg_{0.4}Fe_{0.2}SiO_3$). Amphiboles are added to pyroxene (2/3 of amphibole) and olivine (1/3 of amphibole). Specific Ca/Mg ratios from chemical analyses are those reported by Springer (1980) for the Pine Hill complex, by Miller (1937) and Larsen (1948) for the Santa Ana Mountains, and by Wallawender (1976) for the Los Pinos complex. Values for the Pine Hill complex are means for four groups of rocks that Spinger (1980) designated A, B, C, and D. Rock samples from the three Pine Hill soils were plotted by the percentages of plagioclase, clinopyroxenes, and olivine (symbols PH4, PH5, and PH9).

gabbro with more than about 15 to 20% olivine will have a molar Ca/Mg < 0.7 (Fig. 3), but none of 8 rocks with chemical analyses had Ca/Mg $<$ 1.0 (Larsen 1948).

Wallawender (1976) gave mineralogical and chemical analyses for 18 rock samples from the Los Pinos pluton. Ten are hornblende bearing gabbro, one with a high Ca/Mg ratio (2.98) and a mean ratio of 1.35 for the nine others, plotted in Fig. 3. One of the 18 samples is an anorthosite. Six of the others have olivine $>$10% and four of them have molar Ca/Mg ratios $<$0.7 (Fig. 2). One sample with Ca/Mg = 1.14 seems out of place plotted between 0.3 and 0.4 (Fig. 2), and maybe it is, but it has nearly as much hornblende as olivine.

Springer (1980) showed analyses of 29 samples of gabbro. Only two of them had molar Ca/Mg $<$ 1.0 and one had Ca/Mg < 0.7. He arranged the gabbro into four groups, based on the calcium concentration in the plagioclase: group A, $An_{>85}$; B, An_{70-85}; C, An_{55-69}; and D, $An_{<55}$. The means of the four groups are shown in Fig. 2.

There might have been appreciable additions of aeolian dust, or loess, to the soils developed on gabbro in the Pine Hill area and the Peninsular Ranges. Very fine sand and coarse silt are the major components of aeolian dust (Pye 1995). The main sources of aeolian dust have been the Sacramento Valley, about 40 km from the Pine Hill soil sampling sites, and the coast of the Pacific Ocean, about 60 km from the Peninsular Ranges soil sampling sites. No appreciable amounts of coarse sand are likely to have been carried these distances, but appreciable accumulations of very fine sand are possible in the soils.

Soil Parent Material Influences on Plant Species Distributions

The chemical composition of gabbro is intermediate between ultramafic and granitic rocks. Ultramafic rocks are represented by the base of the triangle in Fig. 2 and granitic rocks (quartz diorite to granite) are more silicic than rocks represented by the left edge of the triangle. Anothosite, represented by the apex of the triangle, is an ancient rock found in California only in the San Gabriel and Orocopia Mountains; it is generally much less calcic than anorthite, which is the plagioclase feldspar with more than 90% Ca and less than 10% Na.

Ultramafic rocks and soils are well known for having unique plant communities and many

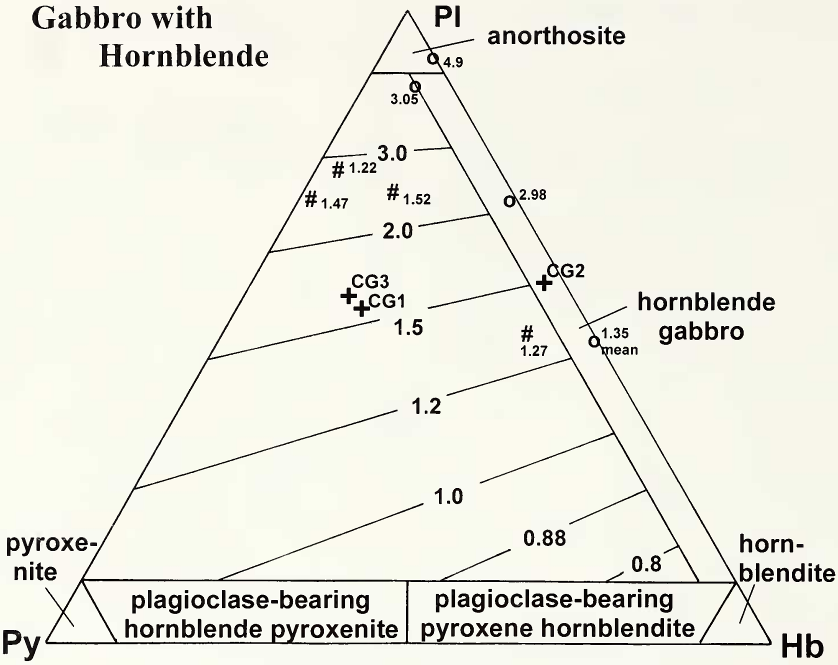

FIG. 3. Hornblende-bearing gabbro. Molar Ca/Mg ratios (0.8–3.0) of gabbro composed of plagioclase (Pl), hornblende (Hb), and pyroxene (Py). Plagioclase is represented by labradorite ($Ca_{0.6}Na_{0.4}Al_{1.6}Si_{2.4}O_8$), hornblende by $Ca_2Mg_3AlFeAl_2Si_6O_{22}(OH)_2$, and pyroxene by augite ($Ca_{0.4}Mg_{0.4}Fe_{0.2}SiO_3$). Symbols as in Fig. 2: o, Los Pinos complex; # Santa Ana Mountains. Rock samples from the three Guatay-Cuyamaca soils were plotted by the percentages of plagioclase, clinopyroxenes, and hornblende (symbols CG1, CG2, and CG3).

endemic species. The absence of many species that are common on soils of more silicic rocks has been attributed to low exchangeable Ca/Mg ratios (Alexander et al. 2007). Some gabbro has low Ca/Mg ratios, but the ratios were not particularly low in the gabbro soils sampled in the Pine Hill area and Peninsular Ranges.

Vegetation differences from gabbro to quartz diorite soils are evident, but not as dramatic as the differences from gabbro to ultramafic soils (Whittaker 1960). More perfuse vegetation on quartz diorite than on gabbro soils (Whittaker 1960) might be explained by greater fertility of quartz diorite soils related to greater amounts of K and P in diorite than in gabbro (Table 1). On a mafic to silicic scale, fertility may be greatest on diorite soils, which generally have a more favorable balance of plant nutrients than either mafic or granitic soils.

An anorthosite soil in the San Gabriel Mountains was sampled and characterized by Graham et al. (1988). Although the parent rock had more than 90% plagioclase, the feldspar was andesine that has slightly more Na than Ca. Nevertheless the soil had much more exchangeable Ca than Na. It had low exhangeable K and presumably low P, although the analyses did not include P.

Vlamis et al. (1954) grew lettuce in 13 soils sampled on gabbro, anorthosite, diorite, and granodiorite. The lettuce responded to N additions on all of the soils and to P on most of them, except on an infertile anorthosite soil where there was no response to a complete N + P + K fertilizer either. Only on an anorthosite soil did the lettuce respond to K addition. Although plant cover appeared to be related to soil productivity, there were no distinct differences in plant species distributions among the soils. Other than sparse trees (*Pinus coulteri* D. Don and *Quercus chrysolepis* Leibm.), only shrubs and *Yucca* sp. were reported from the soil sampling sites; the shrubs were *Adenostoma fasciculatum* Hook. & Arn., *Arctostaphylos* spp., *Ceanothus* spp., *Cercocarpus* sp., *Eriodictyon* sp., *Lotus scoparius* (Nutt.) Ottley, *Quercus* spp., *Malosma laurina* (Nutt.) Abrams, and *Salvia* spp.

METHODS

Gabbro soils and their parent rocks were sampled at two sites with unique vegetation and one without unique vegetation in both Research Natural Areas (RNAs) in the Peninsular Ranges and the Pine Hill Preserve in the foothills of the Sierra Nevada. Altitudes are 460 to 590 m at the Pine Hill sites and 1270 to 1385 m at the Guatay and King Creek RNA sites in the Peninsular Ranges. The mean annual precipitation at these sites is in the 750 to 800 mm range. At a site on the upper one-half of a moderately steep (21–36%

gradient) convex slightly slope in each plant community, three sets of soil and rock samples were taken from subsites three to nine meters apart. The soils were sampled at the 0–15 cm and 30–45 cm depths. Each subsite soil sample was a composite of three subsamples taken from points one to three meters apart. Plants were identified by reference to The Jepson Manual (Hickman 1993) and cover areas were estimated visually. Plant species in a list for the Pine Hill sites were verified by Graciela Hinshaw (Bureau of Land Management, Eldorado Hills, CA) and those in a list for the Peninsular Ranges sites were verified by Todd Keeler-Wolf (California Department of Fish and Game, Sacramento).

Soil samples were dried and sieved to separate the fine-earth (particles <2 mm) for sand and chemical analyses. Texture and consistence of wetted samples were estimated by feel and identified by USDA nomenclature (Soil Survey Staff 1993). Soil family classification follows Soil Taxonomy of the USDA (Soil Survey Staff 1999). Minerals were estimated in 36 fields of view in thin-sections of rocks–one rock from each sample site. Sand was separated from fine-earth samples following treatments overnight in household bleach, decantation of clay, and overnight with Na dithionite in Na citrate solution. Coarse silt (30–62 μm) was obtained from the Pine Hill samples by decantation. Sand separates were dry sieved to obtain five size fractions, and the fine sand (0.125–0.25 mm) fraction was separated into light and heavy grains with bromoform (SG = 2.85). Magnetic grains were separated from the fine sand, very fine sand, and coarse silt fractions with a hand magnet. Percentages of very fine sand and coarse silt with low refractive indices (RI < 1.56) were ascertained by observing 300 grains from each Pine Hill soil.

Soil pH was ascertained with a glass electrode in 1:1 water:soil suspensions. Calcium and magnesium were extracted with molar KCl and measured by atomic absorption (AA) spectrometry. Exchangeable acidity was extracted with 0.5 molar KCl-triethanolamine pH 8.2 buffer and back-titrated with 0.08 molar HCl to a methyl red endpoint (Peech 1965). Soil organic matter was approximated by loss-on-ignition (LOI) at 360°C.

Results of chemical analyses are displayed as means of three samples from each site with standard deviations in parenthesis. One-way ANOVA was run for the three Pine Hill sites and the three Peninsular Ranges sites; that is three sites with three replications at each site in each run of ANOVA. Differences between means in each set of three sites were evaluated by the least significant differences (Snedecor and Cochrane 1967). Where the differences are significant at the 95% level of confidence ($\alpha < 0.05$), the values are designated a and b if the means are on two levels, or a, b, and c if they were on three

Table 2. Site Characteristics, Soils, and Plant Communities. Sites PH are from Pine Hill, El Dorado Co., sites CG are from Cuyamaca-Guataty, San Diego Co.

Site	Lat. (deg. N)	Long. (deg. W)	Alt. (m)	Slope		Precipitation (cm/yr)	Soil	Soil class	Surface stoniness	Plant community
				Aspect	% gradient					
PH4	38.722	120.989	589	NW	26	80	Boomer variant	Clayey-skeletal, smectitic, mesic Ultic Haploxeralf	Slight	Black oak/toyon–Lemmon ceanothus
PH5	38.719	120.988	577	SE	28	80	Rescue, stony	Clayey-skeletal, smectitic, thermic Mollic Haploxeralf	Very stony	Mixed chamise chaparral
PH9	38.719	120.964	458	SE	23	80	Rescue, clayey	Fine, smectitic, thermic Mollic Haploxeralf	Sparse	Chamise-manzanita chaparral
CG1	32.932	116.614	1385	S	21	90	Las Posas, stony	Clayey-skeletal, smectitic, thermic Typic Rhodoxeralf	Extremely cobbly	Cuyamaca cypress/chamise–golden-yarrow
CG2	32.933	116.632	1275	S	36	80	Las Posas var.	Fine, smectitic, thermic Ultic Haploxeralf	Very cobbly	Eastwood manzanita chaparral
CG3	32.849	116.574	1270	N	34	70	Mollisol	Loamy-skeletal, mixed, superactive, thermic Ultic Argixeroll	Extremely stony	Tecate cypress/scrub oak–cupleaf-lilac

TABLE 3. MINERALS (PERCENT BY VOLUME) IN THE ROCKS. Sites PH are from Pine Hill, El Dorado Co., sites CG are from Cuyamaca-Guataty, San Diego Co. [a]Black, opaque minerals, mostly magnetite. [b]Some alteration of feldspars, apparently to clinozoisite.

Site	Pyroxene	Hornblende	Olivine	Feldspar	Opaque[a]	Other
PH4	64	2	10	11	13	Biotite, clinozoisite[b]
PH5	58	trace	3	24	15	Green spinel
PH9	56	1	15	18	10	Biotite, green spinel
CG1	29	17	1	52	1	
CG2	3	34	4	55	4	
CG3	30	12	3	54	1	

levels of magnitude. Where the differences are significant at the 99% level of confidence ($\alpha < 0.01$), A, B, and C are the level designations.

RESULTS

Pine Hill Preserve Sites

Soils at the three sites in the Pine Hill Preserve, two in the Pine Hill unit and one in the Penny Lane unit, are all Alfisols. One site in the Pine Hill unit has a very stony variant of Rescue soil (site PH5) with a mixed chamise chaparral plant community and the other has a clayey variant of Boomer soil (site PH4) with a black oak/toyon–Lemon ceanothus plant community (Table 2). The site in the Penny Lane unit has a clayey variant of Rescue soil (site PH9) with a chamise–manzanita chaparral plant community. Rock samples representing the soil parent materials of these sites are composed of predominantly clinopyroxene, with lesser amounts of plagioclase feldspar and olivine (Table 3). The compositions of these rocks plotted on Fig. 2 indicate that they are expected to have Ca/Mg ratios about 0.5 to 1.0 mol/mol. Sand separates from the soils showed medium (0.25–0.5 mm) and coarse (0.5–1.0 mm) sand modes. Light separates were about 0.2 (20%) of fine sand fractions, comparable to the feldspar estimates in thin-sections (Table 3). About 1/3, or more, of the heavy fine sand separates from sites PH4 and PH5 and about 1/5 to 1/4 from site PH9 were black opaque grains attracted to a hand magnet, suggesting that the black opaque minerals were mostly magnetite. The means of fine sand, very fine sand, and coarse silt from the 0–15 cm depth in soils at the Pine Hill sites were 93, 71, and 33 g/kg and the masses of magnetic grains were 34, 12, and 2 g/kg. Grains with low refractive indices (RI < 1.56) averaged 5, 8, and 11% in these size fractions and about 1% of the grains in the coarse silt fraction were isotropic (presumably volcanic glass) and the isotropic grains were subrounded to rounded, in contrast to other grains which were mostly angular to subangular. Most, or practically all, of the grains with low refractive indices could be feldspars and vein quartz from the gabbro parent rock. Although the glass is presumed to be from an aeolian source, its mass is <0.1% of the mass of the surface (0–15 cm) soil.

The clayey Rescue variant at site PH9 had vegetation that is common on Rescue soils and the soils at sites PH4 and PH5 had unique vegetation (Table 4). Mature Jeffrey pine trees on the north side of Pine Hill are about 38 m tall, indicating moderate site productivity even with the relatively low precipitation on Pine Hill. There are no Jeffrey pine trees on the Rescue soils.

The plants that are local endemics are Pine Hill ceanothus (*Ceanothus roderickii* W. Knight), Pine

TABLE 4. VASCULAR PLANTS ON THE GABBRO SOILS. Botanical authorities are those given in Hickman (1993). PH9 site: *Pinus sabiniana* and *Quercus wizlizenii* occur on adjacent slopes. Abundance symbols: ++++, 30–100%; +++, 10–30%, ++, 3–10%, +, 1–3%; –, trace; 0, none.

	PH4	PH5	PH9
A. Pine hill			
Trees			
Pinus sabiniana	0	–	0
Quercus kelloggii	+++	0	0
Quercus wislizenii	0	+	0
Cercis occidentalis	+	–	++
Shrubs			
Adenostoma fasciculatum	0	+++	++++
Arctostaphylos viscida	+	++	+++
Ceanothus lemmonii	++	+	++

TABLE 4. CONTINUED

	PH4	PH5	PH9
Ceanothus roderickii	0	+	0
Heteromeles arbutifolia	++	++	0
Quercus durata	−	0	0
Rhamnus ilicifolia	+	−	+
Rhamnus tomentella	0	++	+
Salvia sonomensis	0	++	++++
Toxicodendron diversilobum	−	0	0
Eriodictyon californicum	0	−	−
Forbs			
Calochortus albus	0	0	+
Chlorogalum grandiflorum	0	−	−
Chlorogalum pomeridianum	0	−	−
Dichelostemma multiflorum	0	0	+
Dichelostemma volubile	−	0	0
Fritilaria micrantha	−	0	0
Galium californicum ssp. *sierrae*	−	0	0
Galium spp.	+	+	+
Geranium molle	−	0	0
Sanicula bipinnatifida	0	−	−
Senecio (Packera) layneae	0	0	−
Triteleia bridgesii	−	0	0
Wyethia angustifolia	−	0	0
Wyethia reticulata	−	−	0
Grasses			
Avena fatua	−	0	0
Bromus diandrus	−	0	−
Bromus laevipes	+	0	0
Bromus madritensis ssp. *rubens*	−	0	0
Cynosurus echinatus	−	0	0
Elymus glaucus	+	0	0
Elymus multisetus	−	0	0
Fritilaria micrantha	−	0	0
Gastridium ventricosum	0	0	−
Melica sp.	+	0	−
Nassella lepida	−	0	++
B. Cuyamaca-Guatay	CG1	CG2	CG3
Trees			
Callitropis stephensonii	+++	0	0
Callitropis forbesii	0	0	+++
Shrubs			
Adenostoma fasciculatum	+++	++	++
Arctostaphylos glandulosa	+	+++	−
Ceanothus foliosus	0	+	0
Ceanothus greggii var. *perplexens*	−	0	++++
Cercocarpus betuloides	0	0	−
Ericameria parishii	+++	++	0
Heteromeles arbutifolia	+	0	0
Rhamnus crocea	−	+	0
Quercus berberidifolia	++	0	++++
Salvia sonomensis	+	0	0
Subshrubs and succulents			
Eriophyllum confertifolium	++	0	0
Trichostema parishii	+	−	0
Hesperoyucca whipplei	−	0	0
Forbs			
Calystegia collina	−	+	0
Dichelostemma capitatum	+	0	0
Grasses			
Calamagrostis koeleroides	0	+	0

Hill flannelbush (*Fremontodendron californicum* (Torr.) Coville ssp. *decumbens* (R. M. Lloyd) Munz), El Dorado bedstraw (*Galium californicum* Hook. & Arn. ssp. *sierrae* Dempster & Stebbins), and El Dorado mule-ears (*Wyethia reticulata* Greene). All four of these species are present in the vicinity of sites PH4 or PH5 in the Pine Hill unit, but only El Dorado bedstraw and El Dorado mule-ears are present in the Penny Lane unit (G. Hinshaw, U.S. Bureau of Land Management personal communication).

Surface soil Ca concentrations are relatively high on the very stony Rescue variant (PH5) and the Mg relatively high on the clayey Rescue variant (PH9). The Ca/Mg ratios are significantly higher in the very stony Rescue variant than in the other soils, and the organic matter (LOI, Table 5) and exchangeable acidity are higher, also. The relatively high soil organic matter and high CEC (mostly exchangeable Ca and acidity) at site PH5 may be related to a thick O-horizon of predominantly live oak, toyon, and coffeeberry leaves. The O-horizon was not analyzed chemically. Aqua regia digestion recovered relatively low amounts of Ca for the soil at site PH5, raising doubts about the usefulness of results from the digestion. Aqua regia is an aggressive solvent, but it does not recovery the total amounts of all elements in soils.

Peninsular Ranges, Cuyamaca-Guatay Sites

Soils at two sites sampled in the Cuyamaca area (CG1 and CG2) are Alfisols and the one on Guatay Mountain (CG3) is a Mollisol. Site CG1 site is on an extremely stony variant of Las Posas soil with a Cuyamaca cypress/chamise–golden-yarrow plant community; site CG2 is on a yellowish red variant of the dark reddish brown Las Posas soil with an Eastwood manzanita plant community; and site CG3 on a soft, or friable, black soil (a Mollisol) with a Tecate cypress/scrub oak–cupleaf lilac plant community (Table 2). Rock samples representing the soil parent materials of these sites are predominantly plagioclase feldspar, with substantial amounts of clinopyroxene and hornblende, and only minor olivine (Table 3). The compositions of these rocks plotted on Fig. 3 indicate that they are expected to have Ca/Mg ratios about 1.5 mol/mol. Sand separates from the soils showed fine sand (0.125–0.25 mm) modes. Light separates are about 0.6 (60%) of fine sand fractions, comparable to the feldspar estimates in thin-sections (Table 3). About 0.3 (30%) of the heavy fine sand separates were black opaque grains attracted to a hand magnet, suggesting that the black opaque minerals are mostly magnetite.

The yellowish red Las Posas variant at site CG2 has vegetation that is common on Las Posas soils and the soils at sites CG1 and CG3 have unique vegetation (Table 4).

Exchangeable Ca and Mg in the surface and K in the subsoil are relatively high in the Mollisol (site CG3, Table 5). As at site PH5 on Pine Hill, the Mollisol at site CG3 has a relatively thick O-horizon, but the surface soil organic matter content (LOI, Table 5) is higher in the extremely stony Las Posas variant at site CG1 that had been burned a year or two prior to sampling. Differences in element recovery by aqua regia digestion, such as relatively low P content in the yellowish Las Posas variant, may not be related to vegetation distributions.

Potentially toxic elements (Cr, Co, and Ni) are as high in the soil at site CG2 lacking cypress as they are in the soil at site CG3 with Tecate cypress (Table 6). Although P is lower in the soil at site CG2, that might be a result of the denser vegetation and cypress trees at sites CG1 and CG3 recycling more P rather than an indication of lower inherent soil fertility at site CG2.

Discussion and Conclusions

The chemistry of gabbro soils is sufficiently different from others that some plants that grow on them do not grow on soils of either granitic or ultramafic rocks. In both the Pine Hill area and the Peninsular Ranges, chemical differences between the gabbro soils with common vegetation and those with unique vegetation do not appear to explain the differences in vegetation. The soil differences, other than stoniness, appear to be related to differences in the plant communities on them, rather than the reverse. The hypothesis that the exchangeable CaMg ratios of gabbro soils are important in the distributions of unique species is not verified from the chosen sites.

Perhaps the unique plants would grow on all of the gabbro soils sampled, but they have not all been colonized by those plants. The sites lacking unique species are the hottest and driest sites, which may have limited colonization of them. Site PH9 is lower in elevation than sites PH4 and PH5 that have more unique plants, and site GC2 lacking cypress is on a steep south-facing slope at a lower elevation than site GC1 which is also on a south-facing slope.

Some aeolian dust, or loess, may have been added to the coarse silt fractions of the gabbro soils, but these fractions are small. Only 3.3% of the Pine Hill surface soils were coarse silt, not much more than the 1.0% coarse silt at the 15–30 cm depth. The small amounts of alkali (K and Na > Ca) feldspars and sparse quartz in the coarse silt and other particle-size fractions suggests that the contributions of loess have been minor. Any possible aeolian inputs do not alter the fact that four plants are endemic on the Pine Hill gabbro (Wilson et al. 2010) and that in San Diego Co. *Cupressus arizonica* Greene ssp. *stephensonii* (C.B. Wolf) R. M. Beauch (Cuya-

TABLE 5. SOIL PROPERTIES. The laboratory analyses are means of samples from three subsites, with the standard deviations for each site in parentheses. Samples PH are from Pine Hill, El Dorado Co., samples CG are from Cuyamaca-Guataty, San Diego Co. Text. = texture: C, clay; Cb, cobbly; CL, clay loam; L, loam; St, stony; v, very. Cons. = consistence: ss, s, vs for slightly sticky, sticky, and very sticky; sp, p, and vp for slightly plastic, plastic, and very plastic. BS = base saturation, sum of basic cations divided by the cation-exchange capacity as estimated by basic cations plus acidity extracted with a pH 8.2 buffer. LOI = loss-on-ignition at 360°C. Comparisons among sites in each of the two sample areas: subscripts after sample means indicate levels that are significantly different (lower case letters) or highly significant (upper case letters), with subscript o indicating no significant differences (α 0.05).

Sample	Munsell color		Text.	Cons. wet	pH	Exchangeable cations, pH 8.2 (mmol/kg)				Ca/Mg mol/mol	BS %	LOI g/kg
	Dry	Moist				Ca	Mg	K	Acidity			
PH4-A	7.5YR 4/4	5YR 3/4	StL	ss, sp	6.0	$106_a(20)$	$31_a(5)$	$3.1_o(0.8)$	$51_A(10)$	$3.6_a(1.2)$	$73_A(1)$	$4.1_a(0.9)$
PH4-B	5YR 4/5	5YR 3/4	vStCL	vs, p	5.9	$81_o(16)$	$47_o(16)$	$0.5_o(0.1)$	$45_o(9)$	$1.8_a(0.4)$	$74_o(7)$	—
PH5-A	5YR 4/4	5YR 3/4	vStL	ss, sp	5.8	$153_b(17)$	$26_a(3)$	$4.6_o(2.2)$	$116_B(17)$	$6.0_b(1.2)$	$61_B(2)$	$9.9_b(3.0)$
PH5-B	5YR 4/6	5YR 3/4	vStCL	vs, p	5.8	$136_o(30)$	$53_o(18)$	$0.5_o(0.1)$	$55_o(3)$	$2.7_b(0.5)$	$77_o(6)$	—
PH9-A	5YR 4/4	5YR 3/4	L	ss, sp	6.1	$104_a(7)$	$38_b(6)$	$1.7_o(0.7)$	$67_A(6)$	$2.8_a(0.3)$	$68_C(1)$	$5.6_a(0.8)$
PH9-B	2.5-5YR 4/6	5YR 4/6	CL	vs, p	6.2	$116_o(14)$	$79_o(13)$	$0.4_o(0.1)$	$67_o(2)$	$1.5_a(0.1)$	$82_o(2)$	—
CG1-A	7.5YR 4/4	5YR 3/3	vCbL	ss, sp	5.9	$124_A(4)$	$43_a(6)$	$7.2_A(0.3)$	$104_A(4)$	$2.9_a(0.4)$	$62_A(1)$	$7.1_A(0.9)$
CG1-B	5YR 4/5-5/6	2.5YR 3/5	vCbC	vs, vp	5.8	$90_a(17)$	$81_o(18)$	$1.0_A(0.2)$	$85_A(7)$	$1.1_A(0.1)$	$67_o(6)$	—
CG2-A	7.5YR 4/4	5YR 3/4	CbL	ss, sp	5.7	$76_B(18)$	$37_a(6)$	$7.0_A(0.5)$	$56_B(8)$	$2.0_b(0.2)$	$68_B(2)$	$3.9_B(1.2)$
CG2-B	5YR 5/6	5YR 4/6	clay	vs, vp	6.2	$64_b(3)$	$73_o(6)$	$0.9_A(0.3)$	$59_B(3)$	$0.9_A(0.1)$	$70_o(2)$	—
CG3-A	7.5YR 3/3	7.5YR 2/2	vStL	ss, sp	6.1	$171_C(7)$	$62_b(0)$	$5.4_B(0.2)$	$101_A(5)$	$2.8_a(0.1)$	$71_B(2)$	$6.7_C(0.6)$
CG3-B	7.5YR 4/5	7.5YR 3/4	vStCL	vs, p	5.9	$104_a(9)$	$64_o(4)$	$3.1_B(0.4)$	$76_A(2)$	$1.6_B(0.1)$	$69_o(1)$	—

TABLE 6. SELECTED ELEMENTS FROM AQUA REGIA DIGESTION. PH samples are from Pine Hill, El Dorado Co., CG samples are from Cuyamaca-Guataty, San Diego Co. Mg and Fe are measured in g/kg; all others are mg/kg.

Sample	Al	Mg	Ca	V	Cr	Mn	Co	Ni	Cu	Zn	P	Fe
PH4-A	28.2	18.7	8.3	755	212	1089	87	223	212	53	95	—
PH4-B	39.9	8.0	9.1	722	180	1021	81	87	180	35	91	—
PH5-A	37.0	4.7	6.4	1410	116	1404	92	68	116	46	169	—
PH5-B	35.9	6.5	5.4	991	65	867	73	48	65	28	98	—
PH9-A	32.8	7.2	8.0	830	287	1050	85	109	287	31	112	—
PH9-B	33.5	10.8	7.2	607	182	765	68	82	182	18	54	—
CG1-A	35.3	4.5	5.3	101	239	909	35	41	29	39	426	40.4
CG1-B	60.2	4.6	2.6	157	347	1023	58	54	56	31	465	57.2
CG2-A	37.7	4.8	5.1	322	191	922	37	37	27	42	286	73.4
CG2-B	54.3	3.0	2.0	306	125	835	44	25	58	20	233	83.6
CG3-A	19.2	3.2	6.9	230	59	581	19	15	16	33	329	43.8
CG3-B	39.6	4.9	4.1	370	112	1323	48	28	30	51	399	74.8

maca cypress) and *Cupressus forbesii* Jeps. (Tecate cypress) are only on gabbro soils.

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